A GRAVITY SURVEY OF FORT ORD, CALIFORNIA

by

Clarence Gresham Ivey

United States Naval Postgraduate School

THESIS

A Gravity Survey of Fort Ord, California

by

Clarence Gresham Ivey, Jr.

October 1969

A Gravity Survey of Fort Ord, California

by

Clarence Gresham Ivey, Jr.
Lieutenant Commander, United States Navy
B.S.E., Princeton University, 1957

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OCEANOGRAPHY

from the

NAVAL POSTGRADUATE SCHOOL
October 1969

ABSTRACT

In April 1969, 50 different gravity stations on and around the perimeter of Fort Ord, California, were obtained using a LaCoste-Romberg Model G Geodetic Gravity Meter. The density of stations enabled accurate location of 5-mgal contours of Simple Bouguer Anomaly. The major differences found between the new and previously published contours occurred in the west and southwest regions of Fort Ord.

Five stations obtained by an earlier investigator were reoccupied during this study. The differences in observed gravity at these stations ranged from -0.37 mgal to -0.70 mgal.

In an attempt to explain the differences, 11 additional stations were reoccupied in August 1969. Observed gravity differences for these stations ranged from -0.05 mgal to -0.58 mgal. The differences could not be fully explained nor could the earlier study be successfully tied to this study.

Fort Ord lies on a gravity low and is isostatically overcompensated. Further gravity readings are required on the Monterey Peninsula and in the Salinas Valley to adequately define the substructure of Fort Ord.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to Dr. Joseph J. von Schwind who assisted in obtaining the first gravimeter and provided advice and a willing ear as this thesis took form. Mr. H.W. Oliver and Mr. S.L. Robbins, both of the United States Geological Survey, Menlo Park, California, provided instruments, maps, computer programs, and hours of counselling and instruction, all of which are greatly appreciated.

Finally appreciation is expressed to Dr. R.H. Chapman of the California Division of Mines and Geology, San Francisco, California, who made available all the data that had been gathered previously in the area covered by the Santa Cruz Sheet.

I INTRODUCTION

Gravity measurements are made for a number of reasons. Some of these are scientific and some are commercial. The geophysicist uses gravity anomalies as an aid in interpreting the geological substructure of an area. The mining or petroleum geologist is looking particularly for promising structures for commercial exploitation. Geodesists use gravity anomalies as an aid in determining the shape of the earth. Gravity values, once ascertained, may be of future use to the Armed Forces as a means of precise positioning.

The original purposes of this study were (1) to obtain practical experience in conducting a complete gravity survey of an area, (2) to reduce the data obtained to a standard usable form, and (3) to determine the geological substructure of the area surveyed.

The first two objectives were successfully completed. The third purpose was not successfully concluded for the reasons explained in the final pages of this paper.

II. THE SURVEY

A. SELECTION OF AREA

An unsurveyed area close to Monterey, California, was desired so that the survey could be conducted during weekends and half-days that were available. Two possible areas met the above criteria: (1) the northern end of the Santa Lucia Range located to the south of the Monterey Peninsula and (2) Fort Ord, California. The former area is roadless in the unsurveyed areas. Neither the time nor the resources required to conduct a horseback survey of the area was available to

the author. The latter and smaller of the two areas was therefore chosen. Fort Ord has roads covering most of its previously unsurveyed area and its proximity to the Naval Postgraduate School made three-hour field trips practical.

Previous gravity surveys around the perimeter of Fort Ord indicated the existence of a local low Simple Bouguer Anomaly [Bishop and Chapman, 1967], but no observations had been made on Fort Ord to accurately locate the site of the low. Arrangements were made by the author to enter the firing range area to obtain stations which would help delineate this low.

B. EQUIPMENT

Two gravimeters were made available to the author by the U.S. Geological Survey (U.S.G.S.). A LaCoste and Romberg Model G Geodetic Gravity Meter, serial G58, was utilized for all observations made in April 1969. Serial number G143 was used for the August 1969 observations.

Both meters have a range greater than 7000 milligals (mgal), a reading accuracy of ± 0.01 mgal, and a drift rate of less than 1.0 mgal per month. Model G meters are sealed to eliminate any effect from changes in atmospheric pressure and, as a safety precaution, are also internally pressure compensated. The gravity sensor is completely demagnetized and enclosed with a magnetic shield. The entire meter is maintained at a constant temperature while in operation.

A simplified diagram of the basic meter is shown in Fig. 1. The gravity response system consists of a weight on the end of a horizontal beam supported by a zero-length spring. The shock-eliminating springs form a floating pivot, thus eliminating any friction in the

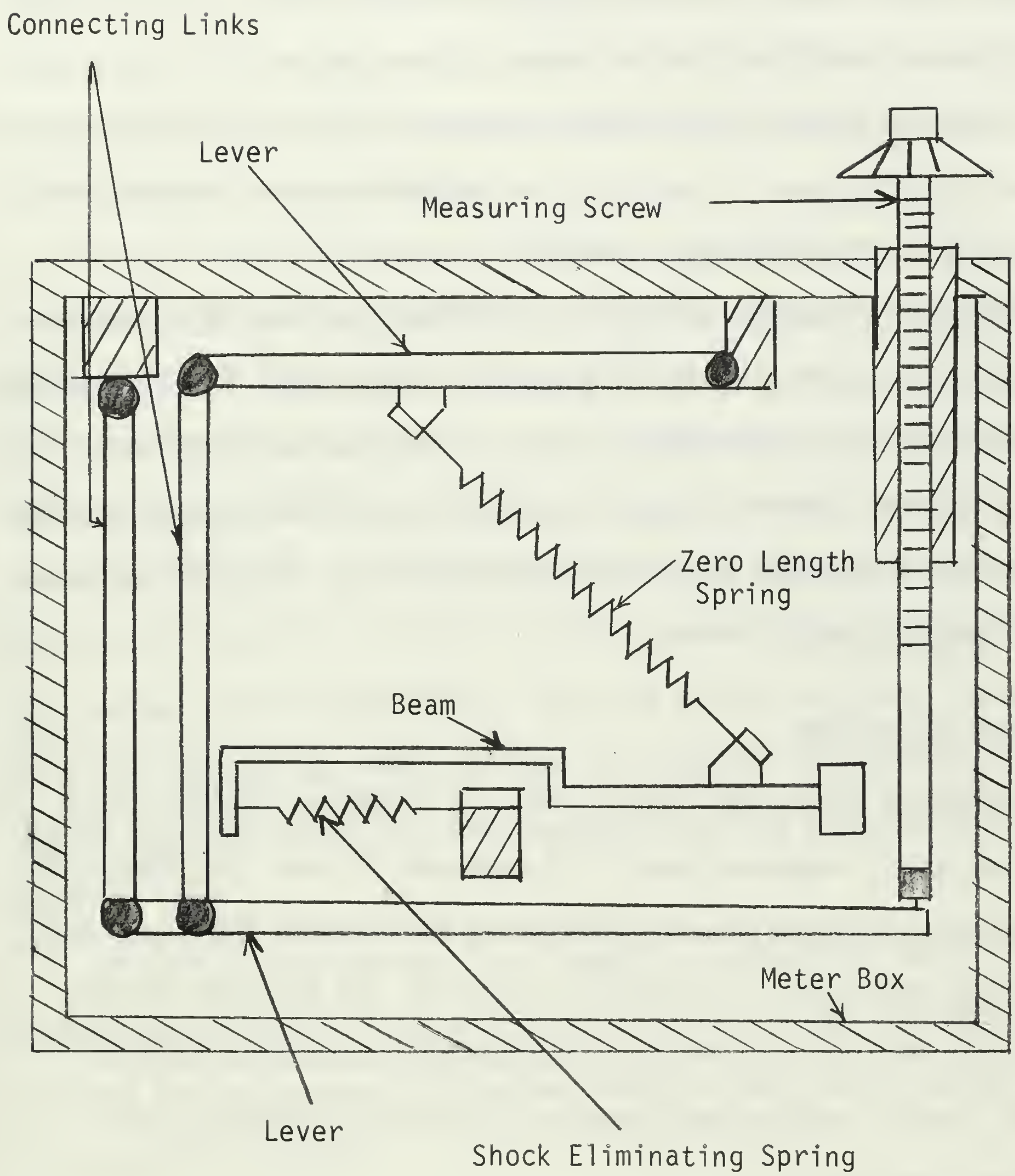


Fig. 1. Simplified Diagram of Meter

moving system. The gravity response system is completely suspended by springs and will withstand any shock that does not damage its housing.

The lever system and measuring screw shown in Fig. 1 are accurately calibrated over their entire range. Since the calibration factors depend only on the quality of the measuring screw and the lever system and not upon any type of auxiliary springs they do not change perceptibly with time [LaCoste- Romberg] .

Topographic maps at a scale of 1:24000 of the Fort Ord area were provided by U.S.G.S. to provide elevation control for the observations. Additional data was provided by the U.S. Army Corps of Engineers from their elevation control surveys conducted by the 663 Engineering Company in April 1962 and by the Sacramento District Corps of Engineers in February and March 1969.

C. DATA COLLECTION

During the period 3-13 April 1969, 51 different stations were occupied on six separate days. For each set of runs the first and last station occupied was the California Division of Mines and Geology Base Station No. 259 (CH259) located at the Monterey Airport.

Of the 51 stations, five were obtained and reported earlier [Sieck, 1964] , one was the base station and the remaining 44 stations were new.

An attempt was made to locate and occupy all monumented bench marks around the perimeter of or on Fort Ord which were shown on the U.S.G.S. topographic maps. Six of 15 were recovered and occupied. The remaining nine monumented bench marks were not found by the author. A few of these had obviously been destroyed by construction and others were most likely concealed by thick vegetation.

The remaining stations were located at non-monumented bench marks shown on the U.S.G.S. topographic maps, monumented bench marks, both permanent and temporary, established by the U.S. Army Corps of Engineers and, in one case at the peak of a hill. This last station was the only one where the elevation was based on a spot elevation rather than a vertical control survey.

At each station occupied the station number, meter reading, time of reading, height relative to the reference elevation, reference elevation, and description of the surrounding terrain were recorded.

At the conclusion of each set of runs the two readings taken at the base station were corrected for tide effects and compared in order to check for tares and to compute drift corrections. The drift was assumed to be linear over the period of the observations. The maximum drift rate used was found to be 0.04 mgal/hr. This drift rate was applied over two stations on 3 August. During the original survey in April the drift rates ranged from 0.00 mgal/hr to 0.02 mgal/hr.

One set of observations on 3 August was discarded due to an apparent tare of about 0.25 mgal, since the drift rate required to account for the change in observed values at the base station would have been 0.10 mgal/hr.

III. GRAVITY CORRECTIONS

Gravity observations must be corrected to reduce the measurements to the value which would be observed on a uniform spheroid fitted as

closely as possible to sea level. This reference spheroid is competely smooth with the vertical distribution of density with depth horizontally uniform.

A. THEORETICAL GRAVITY

The reference spheroid is best approximated by a triaxial spheroid, which is an ellipsoid of revolution modified by depressions along the two 45^0-latitude lines and by a flattening and bulging of the equator [Dobrin, 1960] . The general form of the gravity variation to be expected on such a reference spheroid is given by:

$$g = g_o \left[1 + C_1 \sin^2 L - C_2 \sin^2 2 L\right] \quad (1)$$

where g_o is the value of gravity at the equator at longitude 180^o, C_1 and C_2 are constants which give a measure of the earth's true shape and L is latitude.

The constants are determined by fitting world-wide pendulum measurements of gravity, which have been reduced to sea level, to the formula by the method of least squares. Since 1884 various investigators have determined the value of the constants using measurements available at the time.

The 1930 International constants were used for this study, which when substituted into (1) gives the theoretical gravity (THG) in mgal at any latitude L:

$$THG = 978049 \left[1 + 0.0052884 \sin^2 L - 0.0000059 \sin^2 2L\right] \quad (2)$$

B. TIDAL CORRECTION

Before the actual gravity values as read at each station were reduced to sea level the effect of the orbiting moon was removed. The orbital parameters of the moon are well known and the tidal effect

can be predicted in advance. The tidal gravity corrections were determined by use of the tables and nomogram of the Service Hydrographique de la Marine and Compagnie Generale de Geophysique [1968].

The tidal correction and instrument drift correction were combined and added to the measured value of gravity to obtain the observed gravity.

C. FREE AIR CORRECTION

The next correction that was made to the measured gravity was the free air correction (FAC). This correction assumes the existence of only air between the station and sea level and accounts only for the difference in elevation.

The correction in mgal applied for this survey was:

$$FAC = \left[0.09411549 - 0.000137789 \sin^2 L \right] E$$
$$0.0000000067E \qquad (3)$$

where E = elevation in feet of station above sea level.
[Scheibe and Howard, 1964] (See Appendix 1 for a derivation of this correction.)

D. BOUGUER CORRECTION

An adjustment must be made for the oversimplification of assuming only air exists between the station and sea level. This was done by assuming that a slab of density ρ, thickness E and extending infinitely in all horizontal directions exists between the station and sea level. The effect of this slab is called the Bouguer Correction (BC) and is given in mgal by:

$$BC = 2\pi\gamma\rho E = 0.012774\,\rho E \qquad (4)$$

where ρ = density in g/cm^3

γ = univeral gravitational constant

[Grant and West, 1965 and S. L. Robbins, personal communication]

E. TERRAIN CORRECTION

Another correction was required to account for the fact that there is not a uniform slab, whose upper surface is the "Bouguer plane", but rather there is the actual topography of the land in the vicinity of the station. Both the material extending above the hypothetical slab and the material missing from the slab due to the actual topography result in a reduction of the measured gravity values. Hills reduce the value because the mass opposes the attraction at the station due to the mass of the earth, and the valleys also cause a reduction because they were included in the Bouguer correction, but in fact are not there. These corrections are added to the observed gravity.

In theory the volume and average density of each variation from the Bouguer plane must be calculated and its effect on the station as a function of distance must be determined. In practice a template is used which divides the area in the vicinity of the station into compartments. The template consists of concentric circles with each annular ring divided into compartments. In general the number of compartments in each ring increases with increasing radius. The average elevation in each compartment is determined by visual inspection. The absolute value of the difference in elevation between the compartment and the station is used to enter a correction table which provides the applicable correction for a given assumed density.

Hayford-Bowie templates were used throughout this survey through Zone F. For terrain corrections at distances between 2.29 km and 166.70 km from the station, the U.S.G.S. computerized Terrain Correction Program was utilized.

The principle features of this program are that topography is digitized on a latitude and longitude grid, compartments are assembled on the basis of map boundaries and an exact tie to a circular inner boundary (the outer radius of zone F) is made.

All terrain corrections (TC) were based on an assumed density of 2.67 gm/cm^3.

F. CURVATURE CORRECTION

A final correction was required to account for the curvature of the earth. The Bouguer correction assumes a flat earth which is a reasonable assumption for short distances, but is inaccurate for the greater distances utilized by the computerized Terrain Correction Program.

Lambert [1930] developed the curvature correction (CC) to account for the fact that the earth is not flat. Although he computed the correction to four significant places in the first term, he utilized the value of π only to three significant places. U.S.G.S. has recomputed the correction [S. L. Robbins, personal communication] and found it to be in mgal:

$$CC = 0.0004462E - 3.282 \times 10^{-8} E^2 + 1.27 \times 10^{-15} E^3 \qquad (5)$$

IV. GRAVITY ANOMALIES

A gravity anomaly is the residue left after corrections have been applied to the observed gravity and the theoretical gravity has been subtracted from the result. There are different names for gravity anomalies, depending upon which corrections have been applied.

A. FREE AIR ANOMALY (FAA)

This anomaly is given by:

$$FAA = OG + FAC - THG \quad (6)$$

B. SIMPLE BOUGUER ANOMALY (SBA)

The SBA is given by:

$$SBA = OG + FAC - BC - THG \quad (7)$$

It is this anomaly that is normally used for comparative purposes and that which is plotted on Fig. 3 to Fig. 27.

C. COMPLETE BOUGUER ANOMALY (CBA)

When all corrections discussed above are included the result is the Complete Bouguer Anomaly:

$$CBA = OG + FAC - BC + TC - CC - THG \quad (8)$$

V. DATA REDUCTION

Manual corrections for tide, drift and terrain corrections through Hayford-Bowie Zone F were computed by the author. All other data reduction was accomplished by existing U.S.G.S. Gravity Reduction Programs on the U.S.G.S. IBM 360 Computer. The results are summarized beginning on page 48 .

VI. RESULTS

As shown in Fig. 2 to 27 a local Simple Bouguer Gravity low of -35 mgal exists in the extreme eastern portion of Fort Ord. This low decreases to the southwest, becoming zero at approximately the Monterey - Seaside line and continuing positive to the southwest.

On Fort Ord itself the SBA ranges from - 5.05 mgal to -35.59 mgal. A value of - 38.52 mgal was located on Reservation Road which runs between Salinas and Marina forming the eastern boundary of Fort Ord.

The large number of stations in the relatively small area allowed the 5-mgal contours of SBA to be accurately located. The new contours agree well with the contours plotted by Bishop and Chapman [1967] in the eastern portion of Fort Ord.

In the western and southwestern area there are major changes in the contour location. These changes are attributed to the greater saturation of stations made during this study.

During April 1969, five stations were recovered which had been obtained previously and reported by Sieck [1964] . Table I compares the values of observed gravity at these five stations.

An attempt was made to account for the observed differences, but no satisfactory explanation was evident. The first and most obvious explanation was that CA 879, CA 883 and CA 843 were obtained on one day and the remaining two stations were measured on another day. Ivey's data shows that CA 890 and CA 843 were surveyed on April 6, 1969, and the remaining three stations were occupied on April 3, 1969. Sieck's data does not include dates, but the numbers he assigned to the original stations suggest that CA 884 and CA 883 were surveyed on the same day, CA 879 and CA 890 on some other day and CA 843 on still another day. No correlation between observed gravity and the date of the measurement could be found.

A portion of the observed differences may possibly be attributed to the fact that Sieck used Worden gravimeters provided by U.S.G.S. These meters can not be read to better than ± 0.1 mgal and a figure

of ± 0.15 mgal is probably more realistic. Further, Seick established four base stations in the area for his use, and tied them to CH 176 (Woollard Station WU-3) located at Stanford University.

COMPARISON OF OBSERVED GRAVITY MEASURED AT FIVE STATIONS

Station	OBSERVED GRAVITY (+979800 mgal) SIECK	IVEY	Difference
CA 879	62.92	63.40	-0.48
CA 884	40.07	40.81	-0.64
CA 883	49.73	50.11	-0.38
CA 890	43.05	43.75	-0.70
CA 843	33.50	33.87	-0.37

TABLE I

The calibration error for the U.S.G.S. Worden gravimeters has been determined to be one in six hundred. Thus for every six mgal difference in gravity between two stations the meter will introduce an error of 0.01 mgal. The difference in gravity between Stanford and Fort Ord is about 78 mgal which would produce an error of approximately 0.13 mgal.

If both of the above errors are additive a possible error of about 0.33 mgal may exist in Sieck's data. To confirm this, during the period 1 - 3 August 1969, an additional 11 stations occupied by Sieck were recovered by Ivey. These 11 stations were those in Marina, Seaside, Spreckles and Salinas (west of US 101) Quadrangles that could be found. Table II shows a comparison

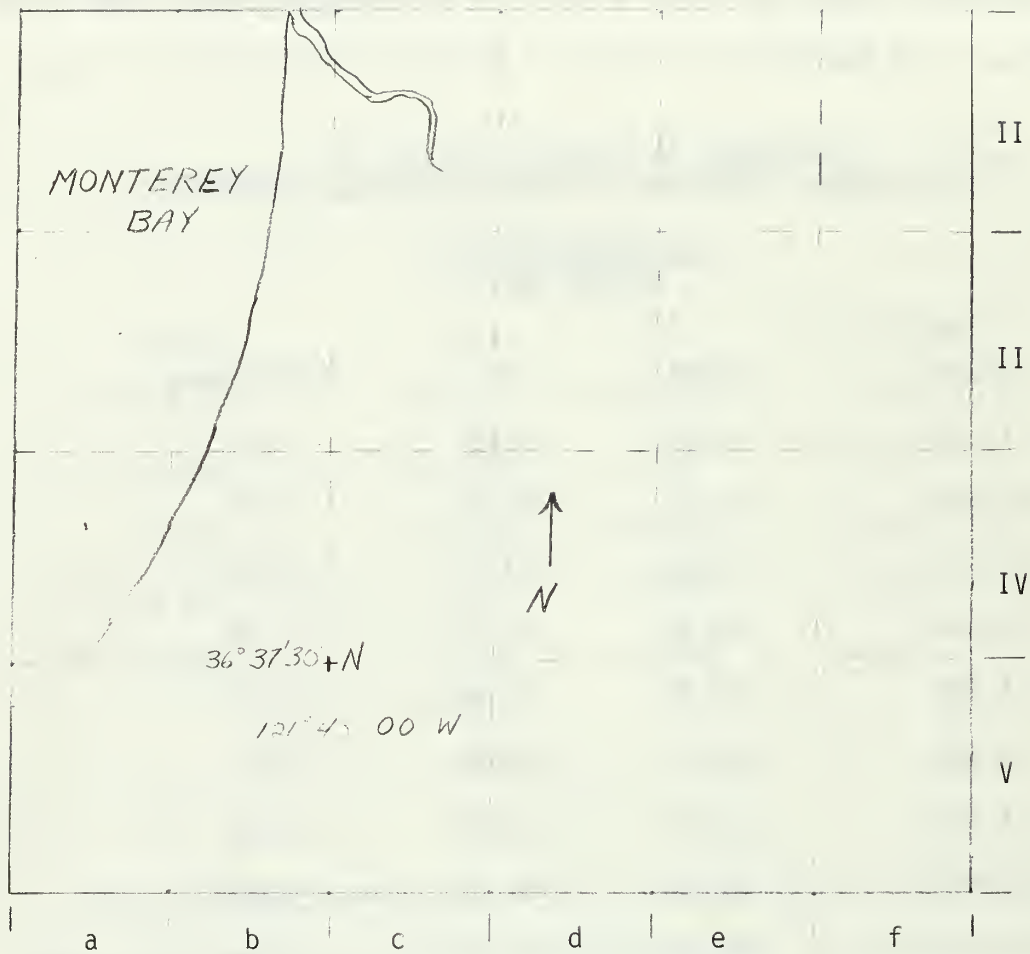
of observed gravity as measured at these 11 stations. If the same errors are assumed to apply to Seick's data the differences range from + 0.38 mgal to - 0.25 mgal.

COMPARISON OF OBSERVED GRAVITY AT
11 DIFFERENT STATIONS IN MONTEREY-SALINAS VICINITY

Station	OBSERVED GRAVITY (+ 979800 mgal) SIECK	IVEY	Difference
CA 845	58.30	58.25	0.05
CA 844	62.20	62.27	-0.07
CA 716	57.50	57.63	-0.13
CA 873	58.40	58.56	-0.16
CA 702	59.70	59.88	-0.18
CA 886	28.73	28.95	-0.22
CA 709	45.70	46.06	-0.36
CA 842	42.70	43.07	-0.37
CA 847	56.80	57.26	-0.46
CA 850	86.20	86.74	-0.54
CA 849	64.80	65.38	-0.58

TABLE II

In addition to the above comparisons, two runs were made between CH 258 and CH 259 as a further check on the latter to eliminate a possible source of error due to an incorrect value of gravity being used for the base station. The average of the two runs showed a difference of observed gravity between the two stations of 0.01 mgal less than the value published by Chapman [1966].



Note:
i) Plate I covers entire area
ii) Plates IIa - Vf cover areas indicated

Fig. 2 Diagram of Survey Area Showing Area Coverage by Photographic Plates

FIG. 4. Plate 1

Fig. 4. Plate IIa

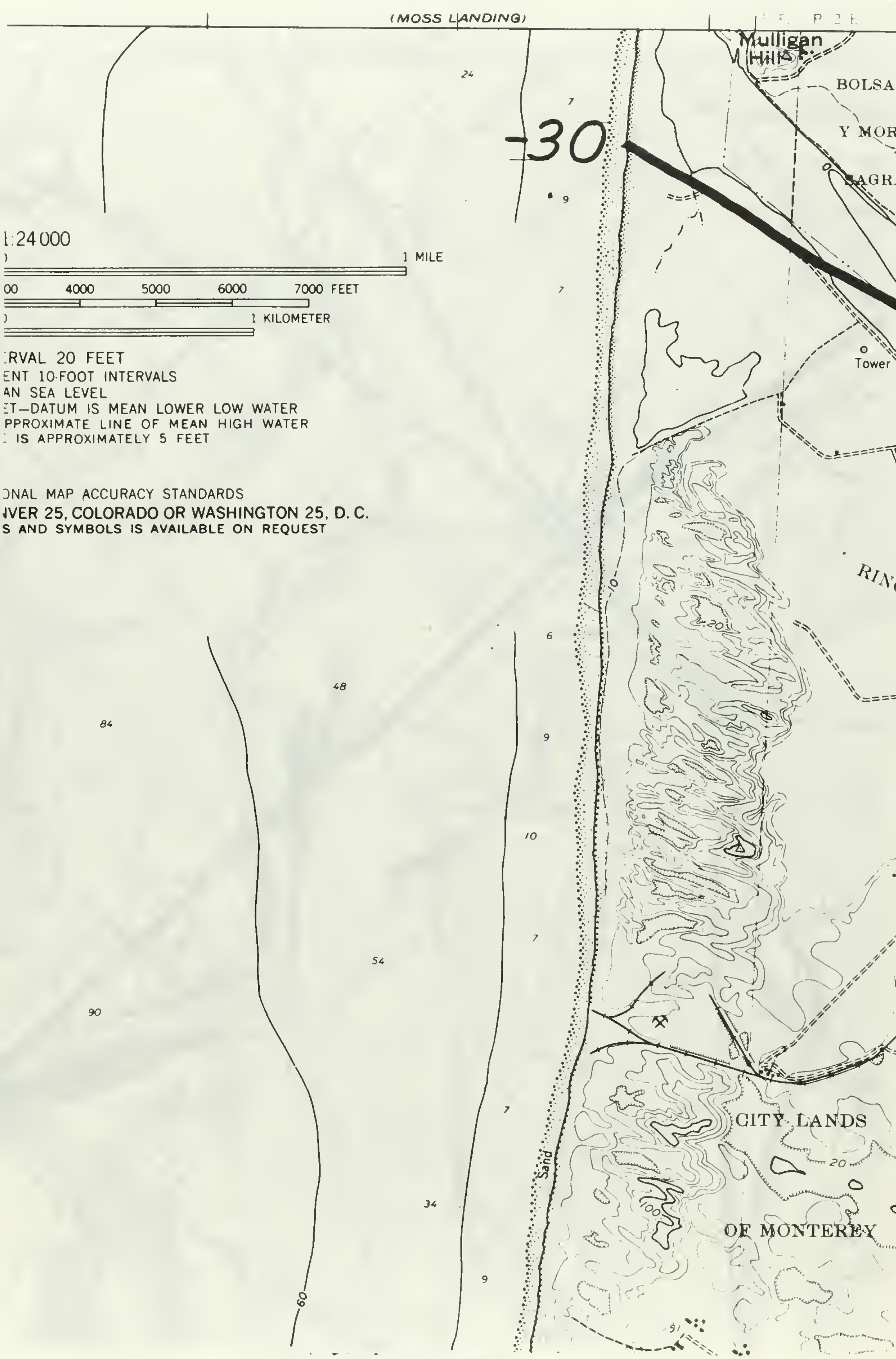


Fig. 5. Plate IIb

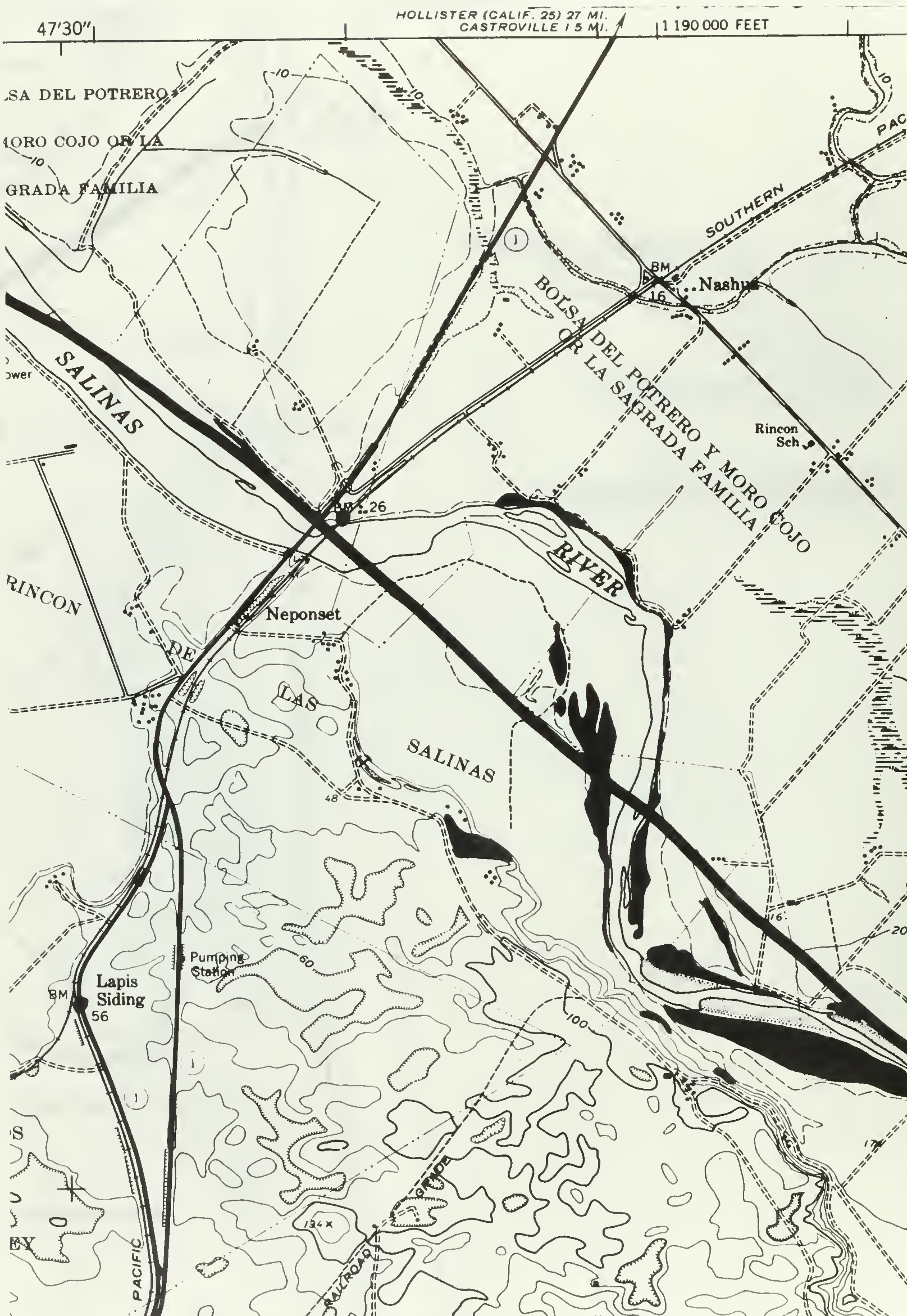


Fig. 6. Plate IIc

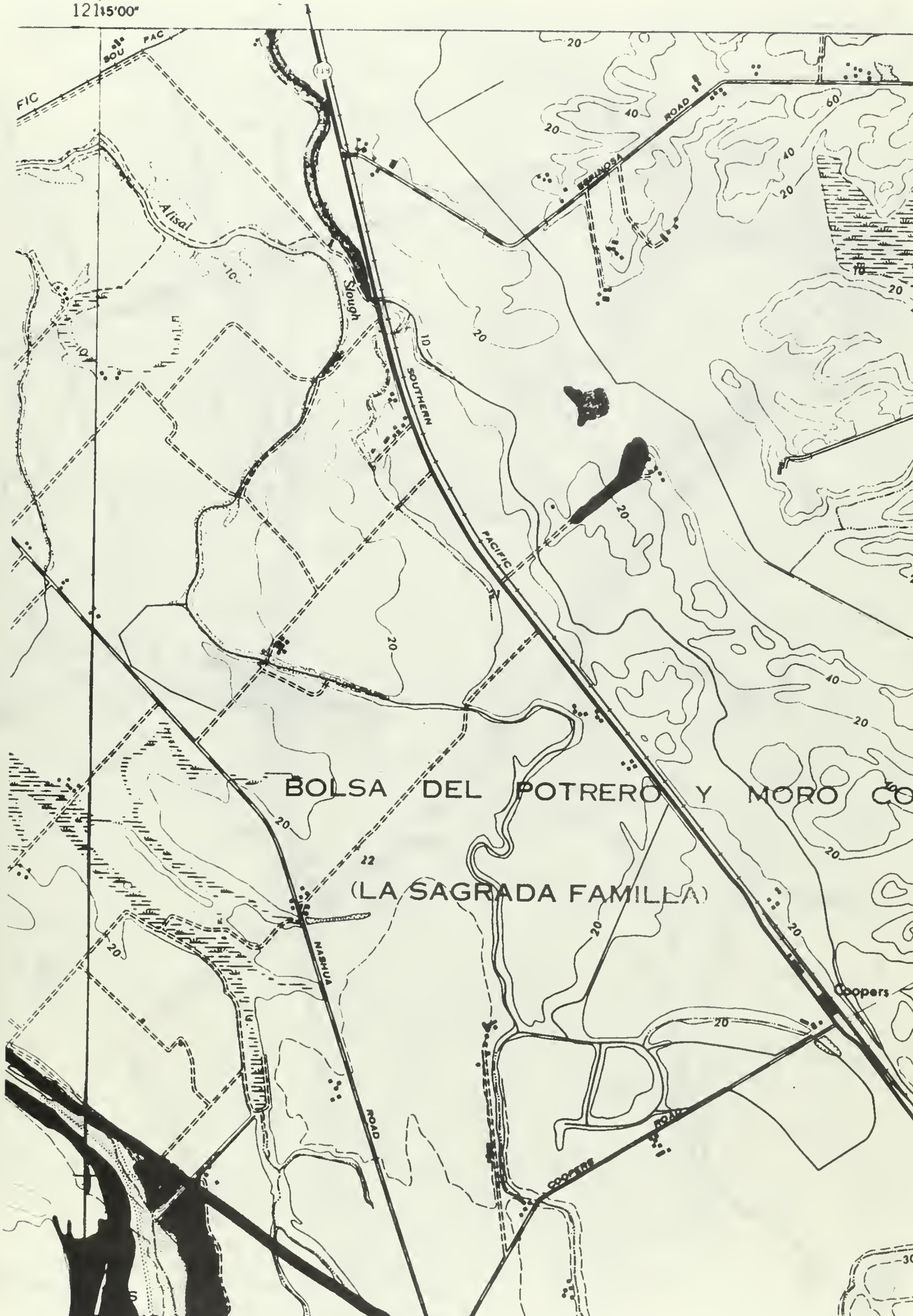


Fig. 7. Plate IId

Fig. 8. Plate IIe

Fig. 9. Plate IIf

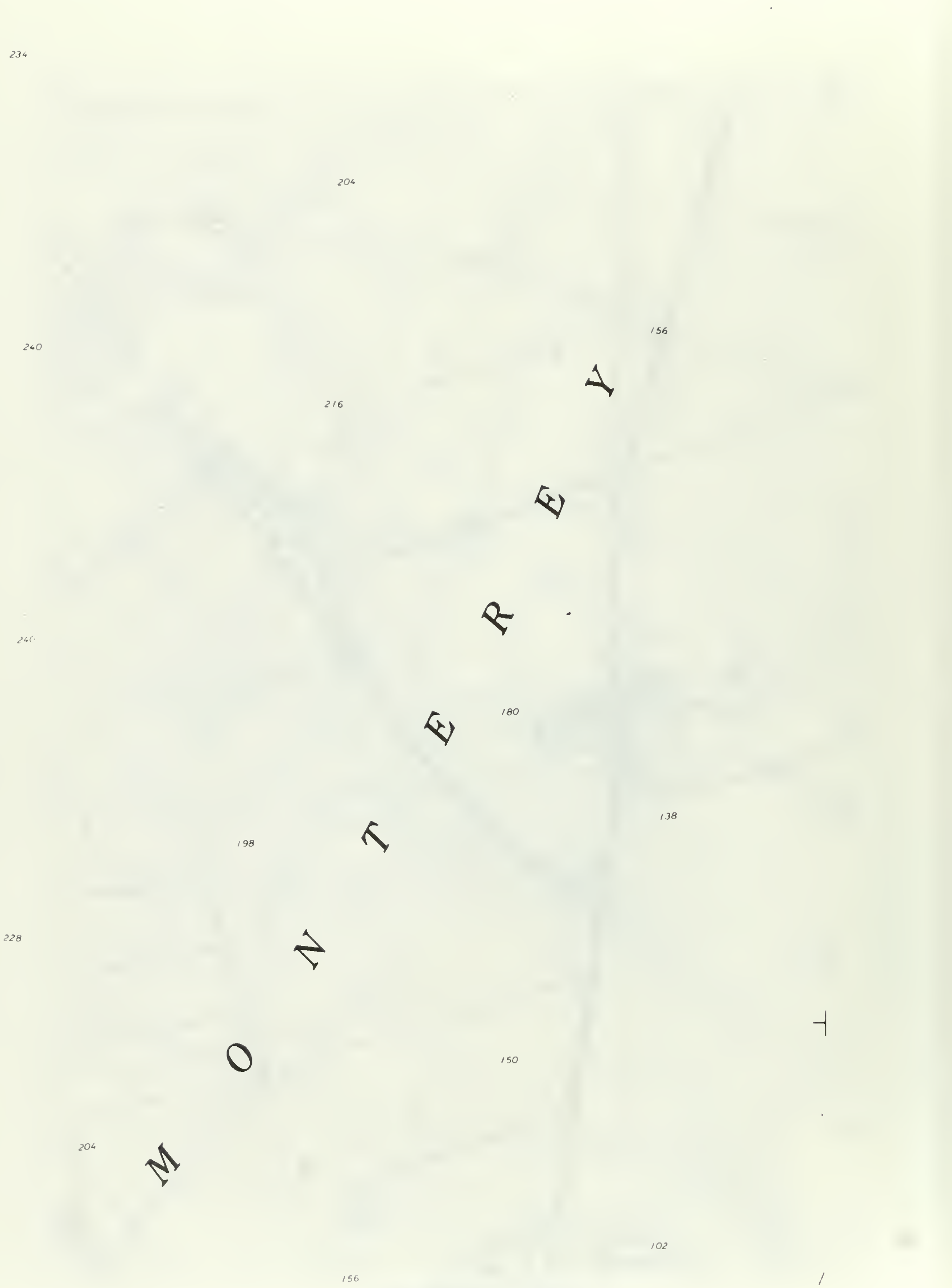


Fig. 10. Plate IIIa

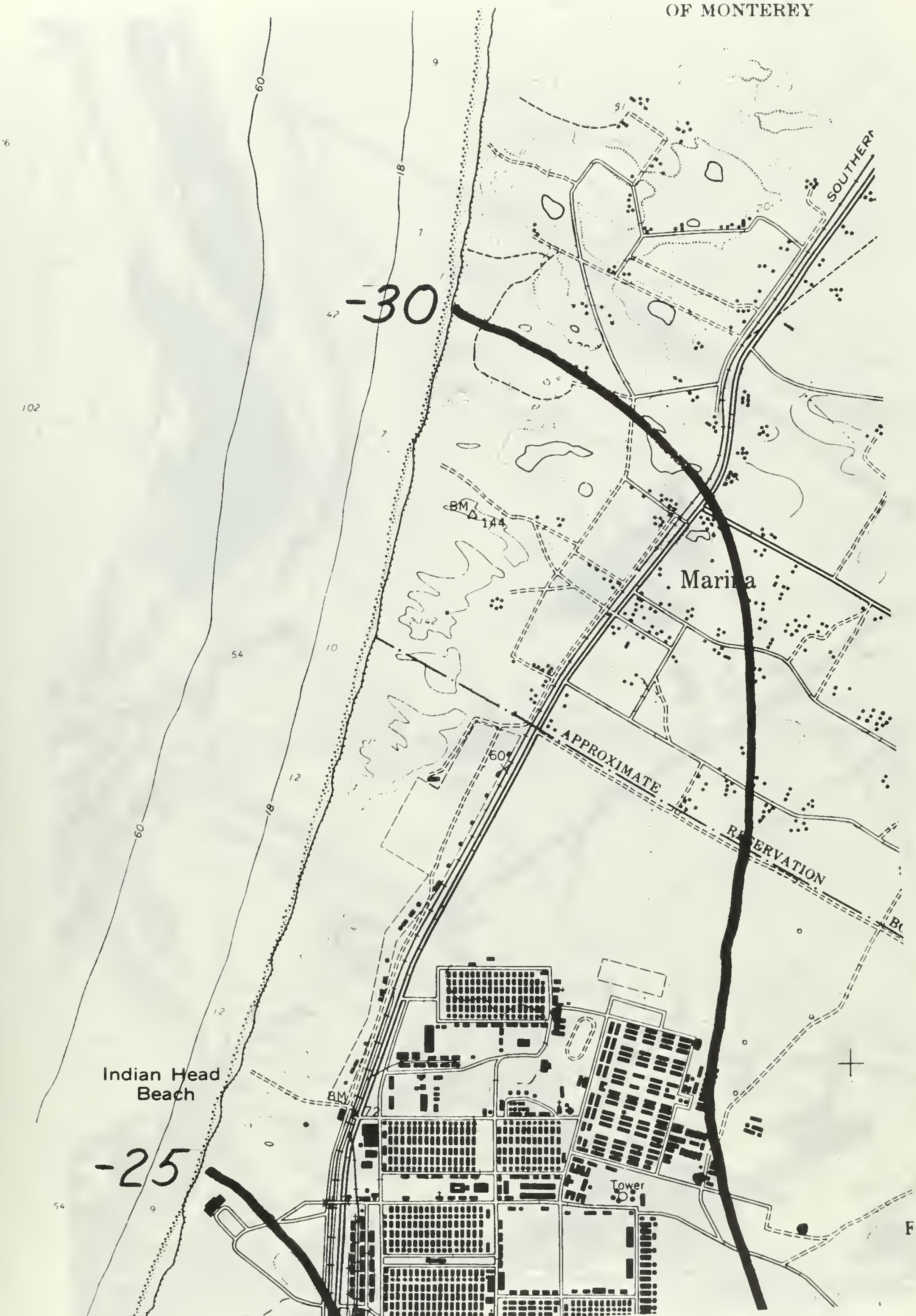


Fig. 11. Plate IIIb

Fig. 12. Plate IIIc

Fig. 13. Plate IIId

Fig. 14. Plate IIIe

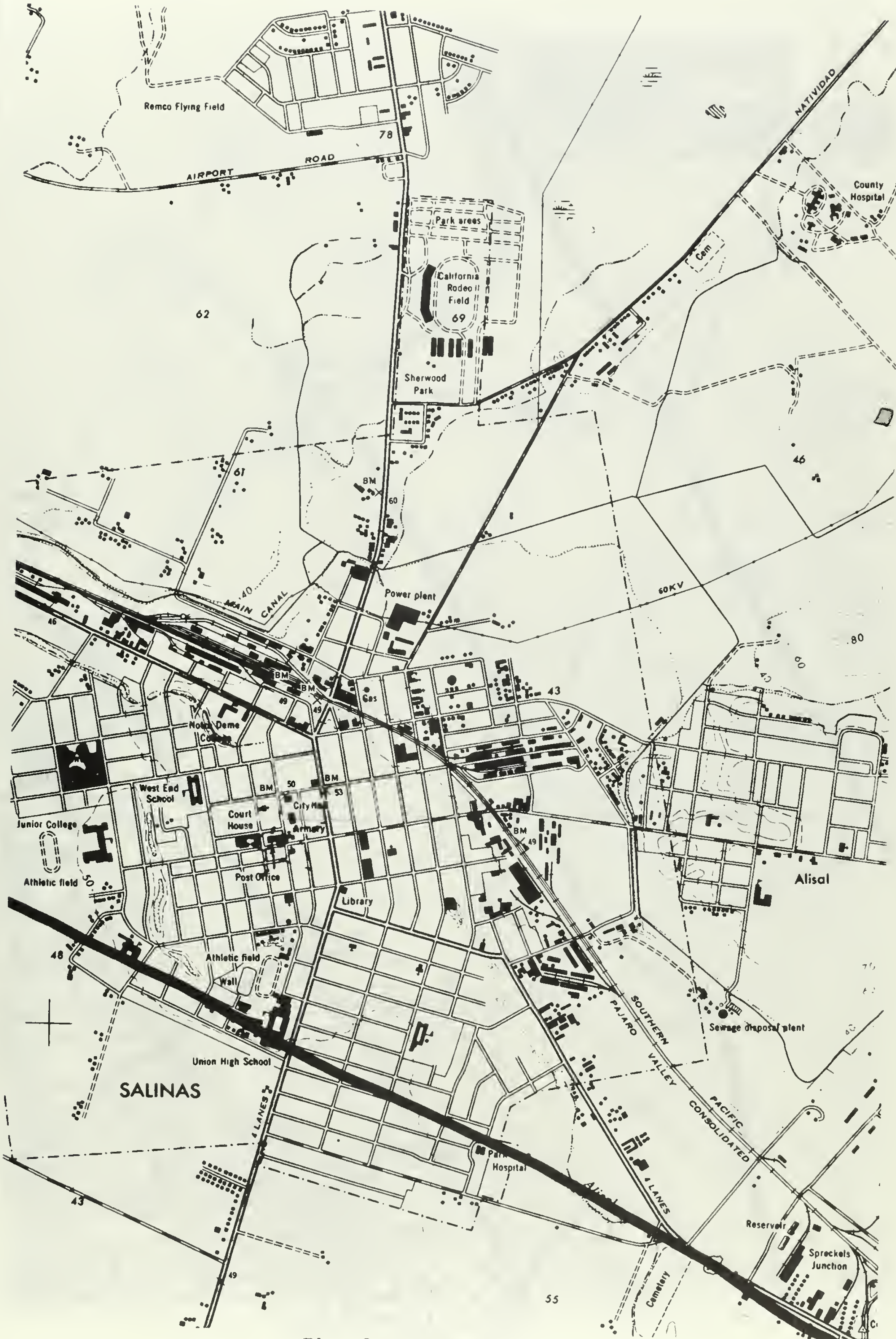


Fig. 15. Plate IIIf

Fig. 16. Plate IVa

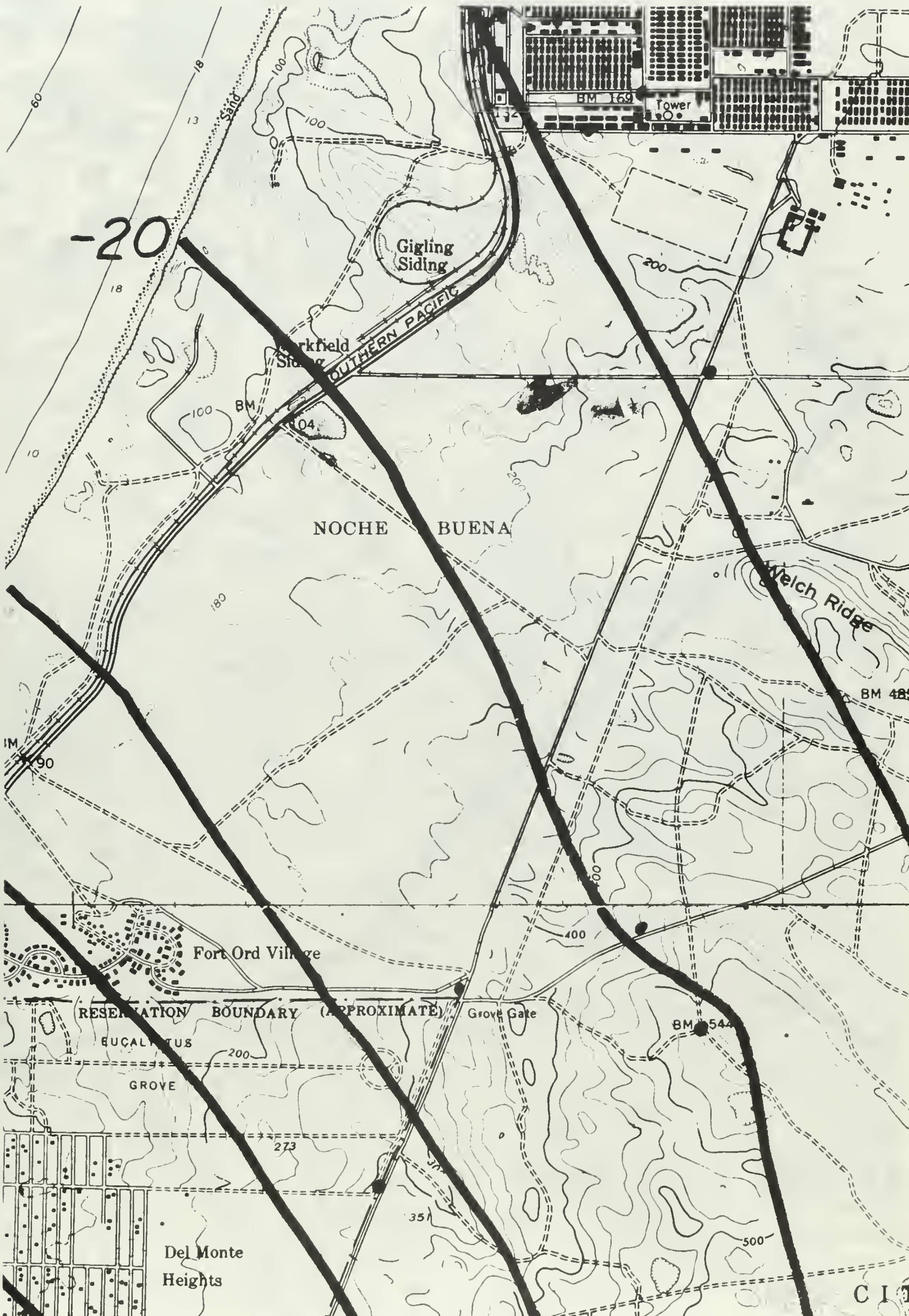


Fig. 17. Plate IVb

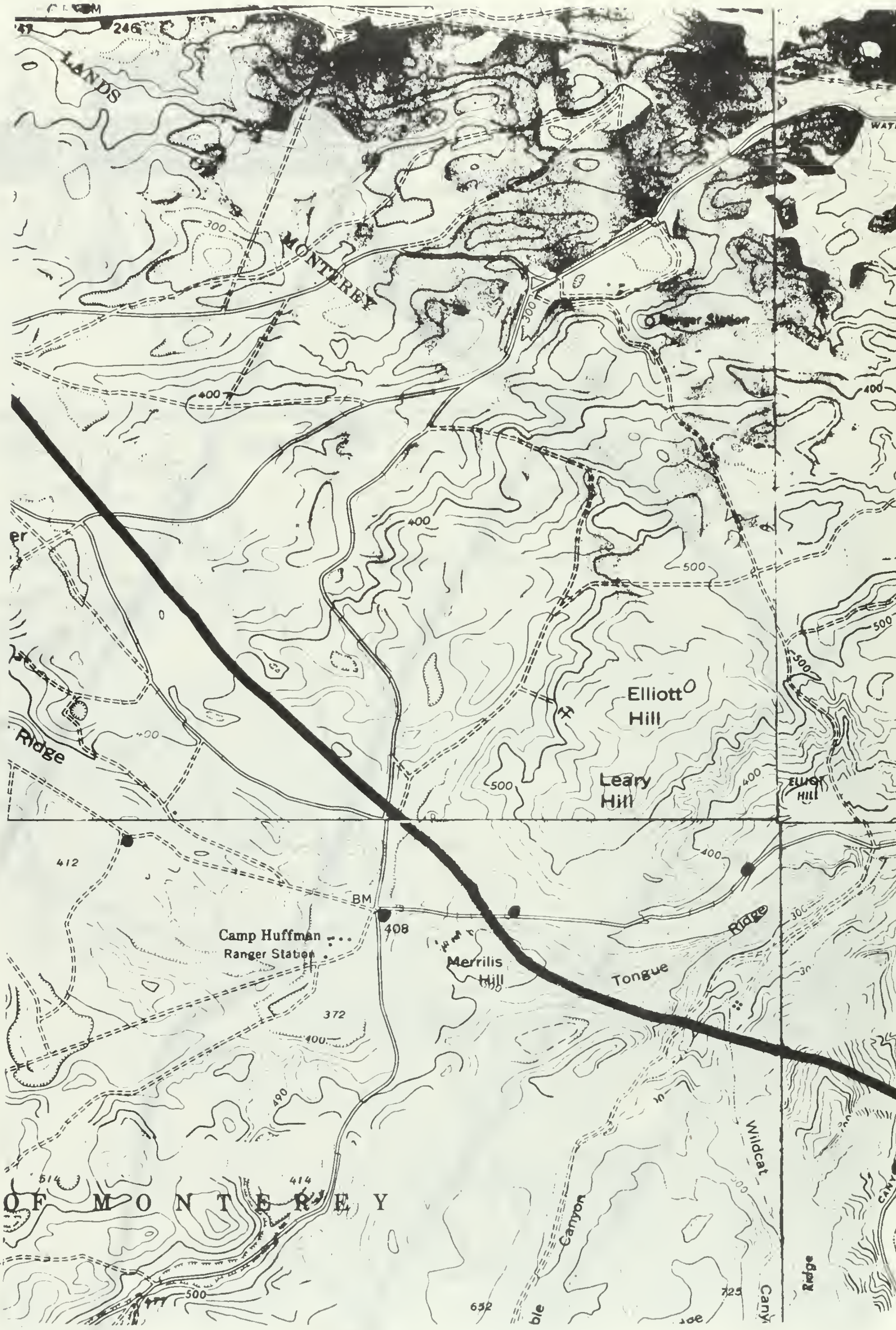


Fig. 18. Plate IVc

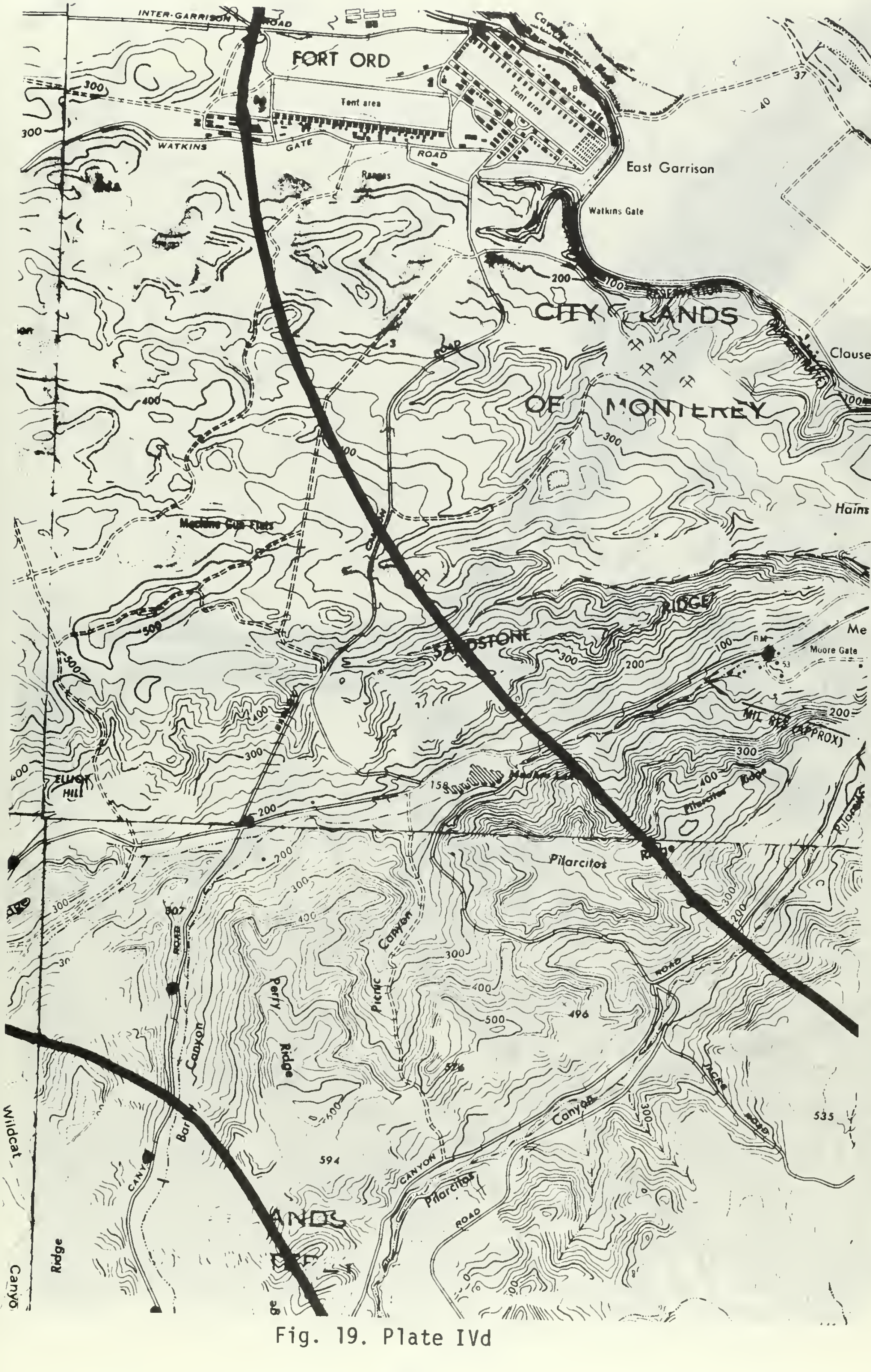


Fig. 19. Plate IVd

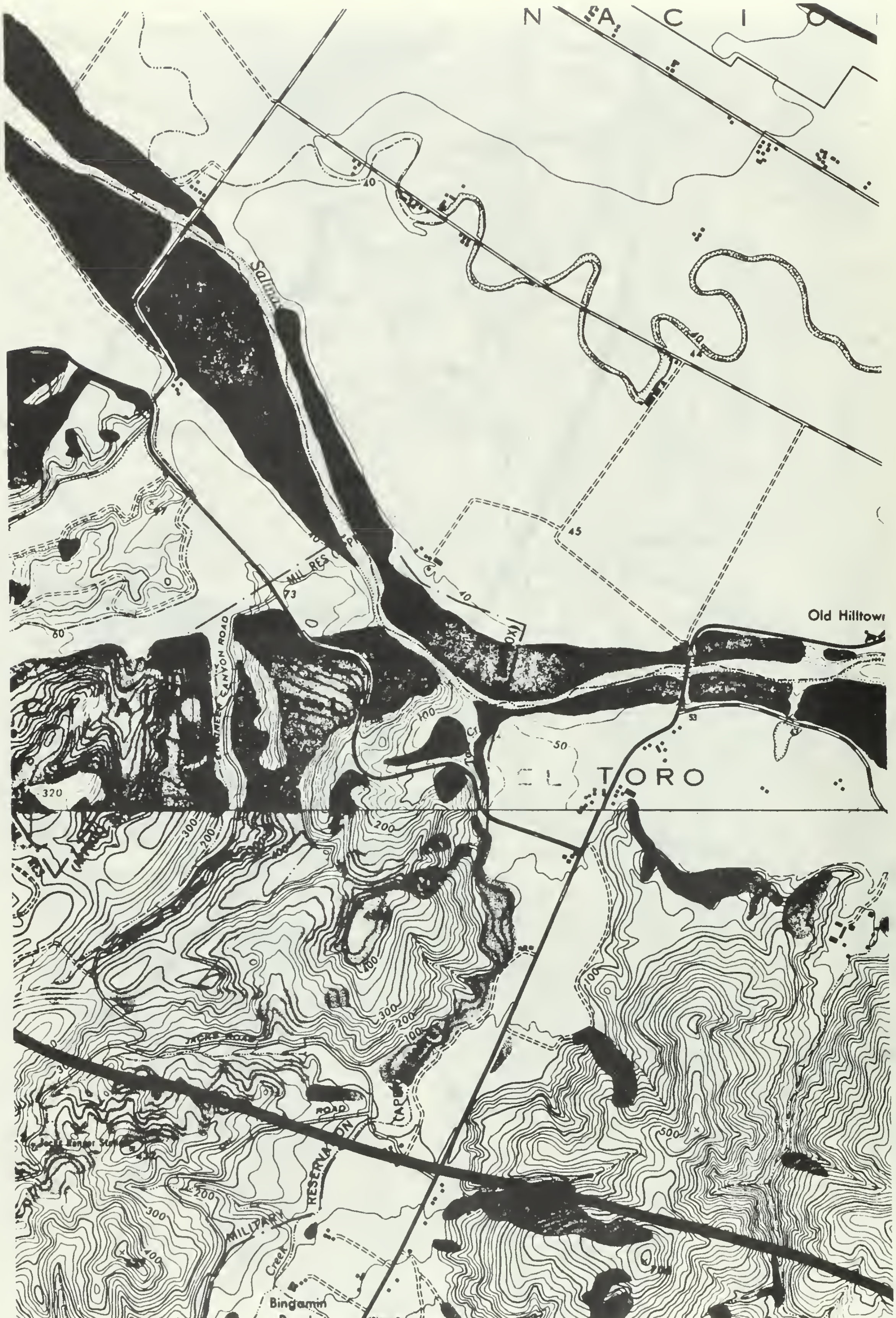


Fig. 20. Plate IVe

Fig. 21. Plate IVf

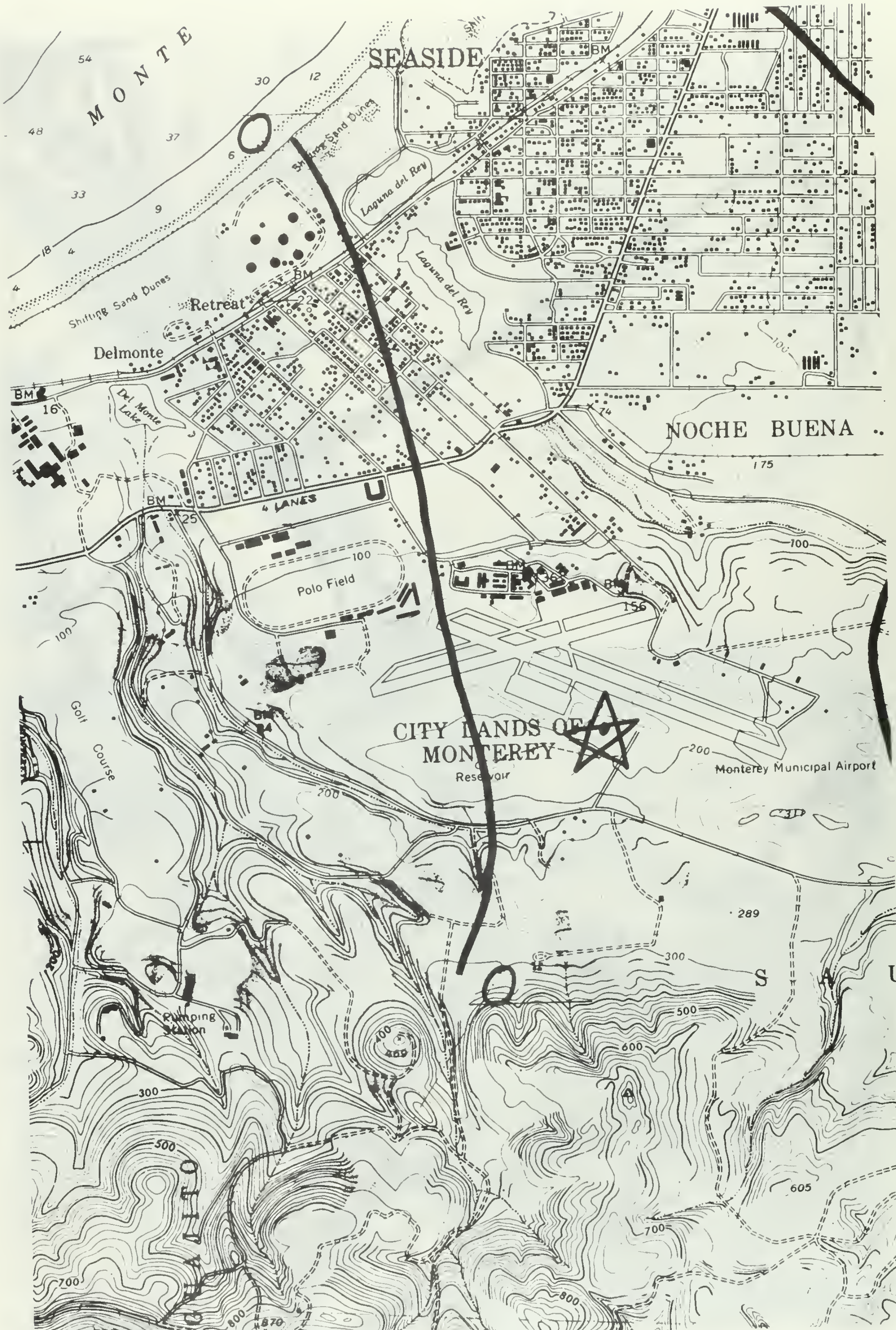


Fig. 22. Plate Va

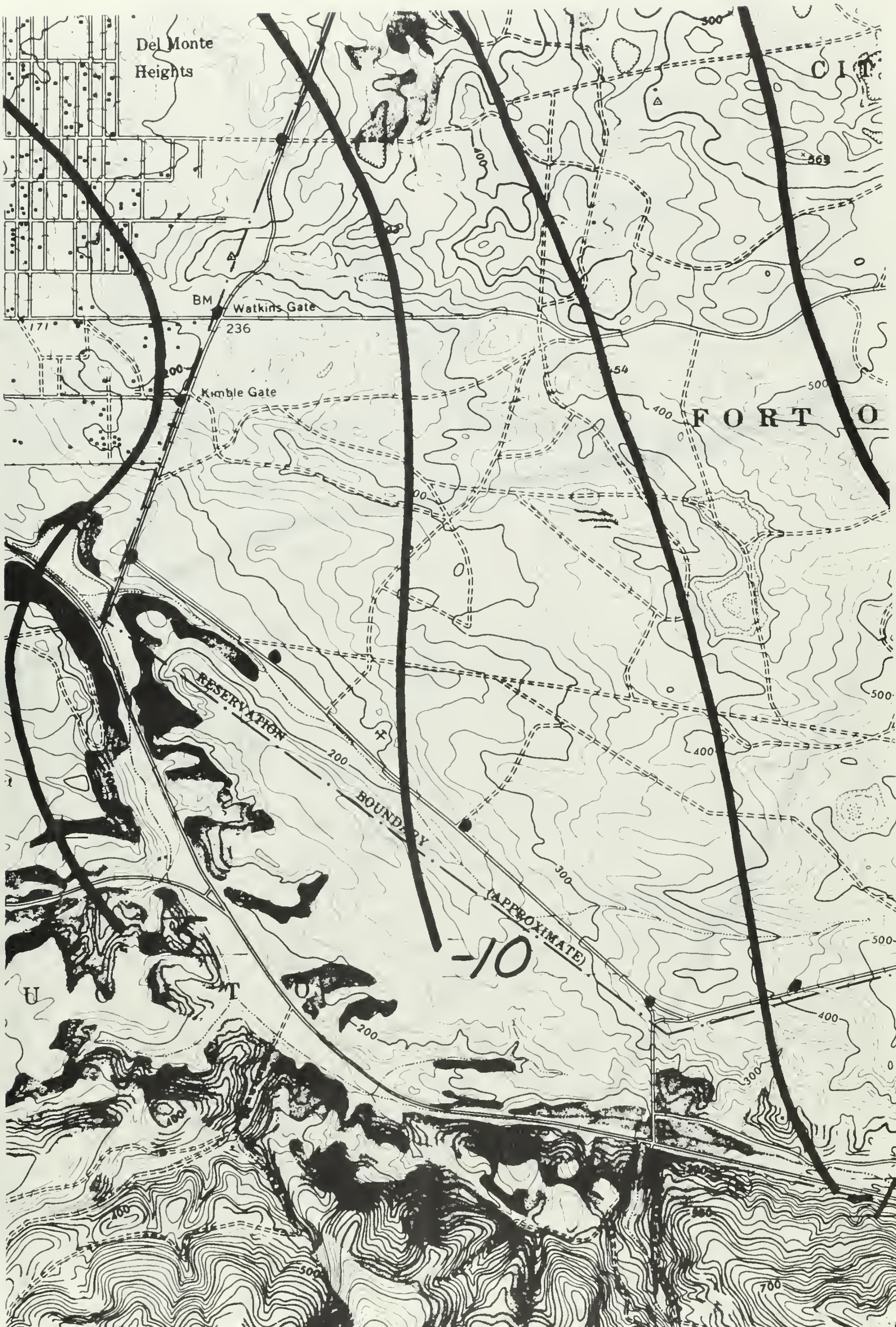


Fig. 23. Plate Vb

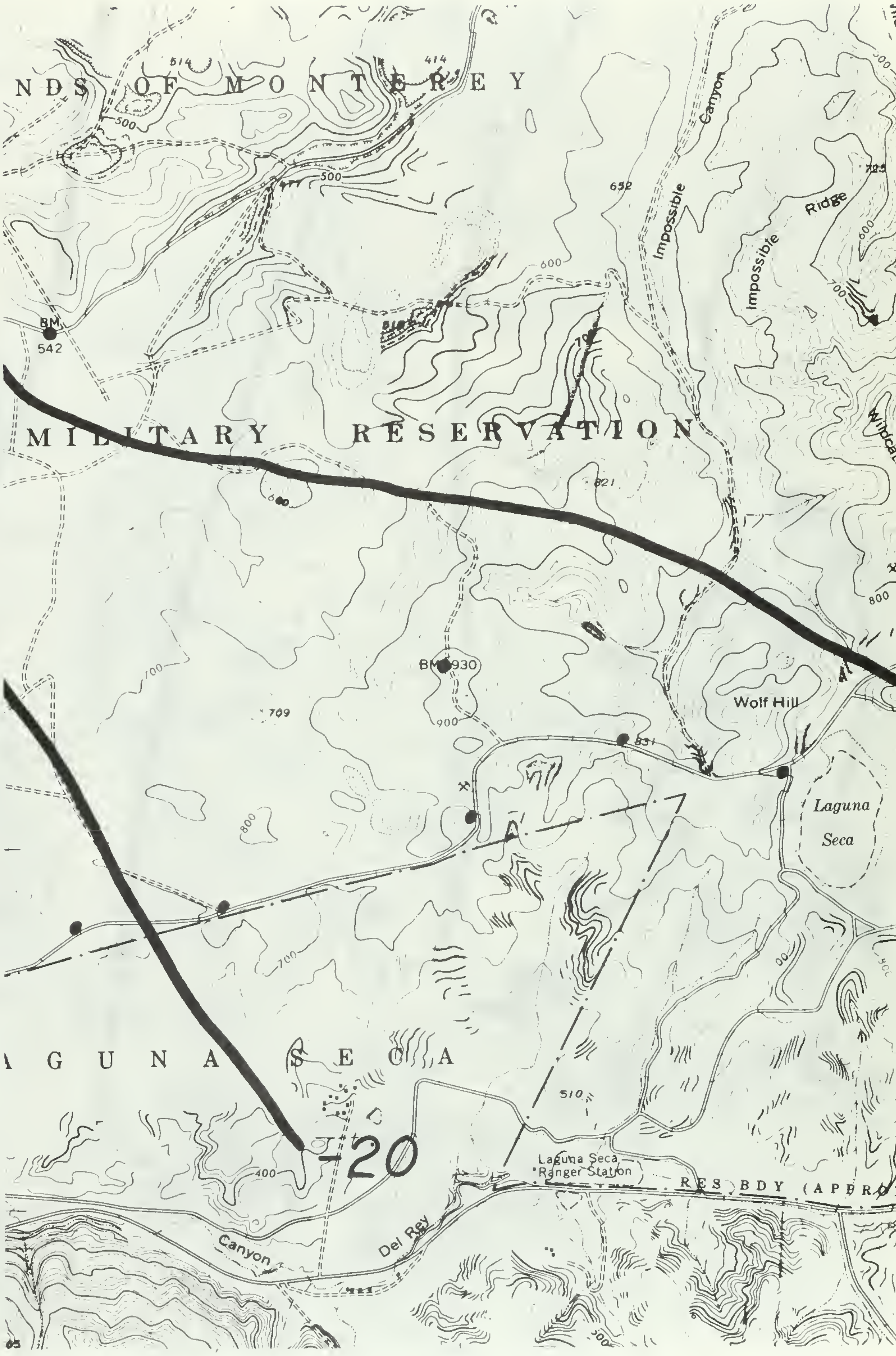


Fig. 24. Plate Vc

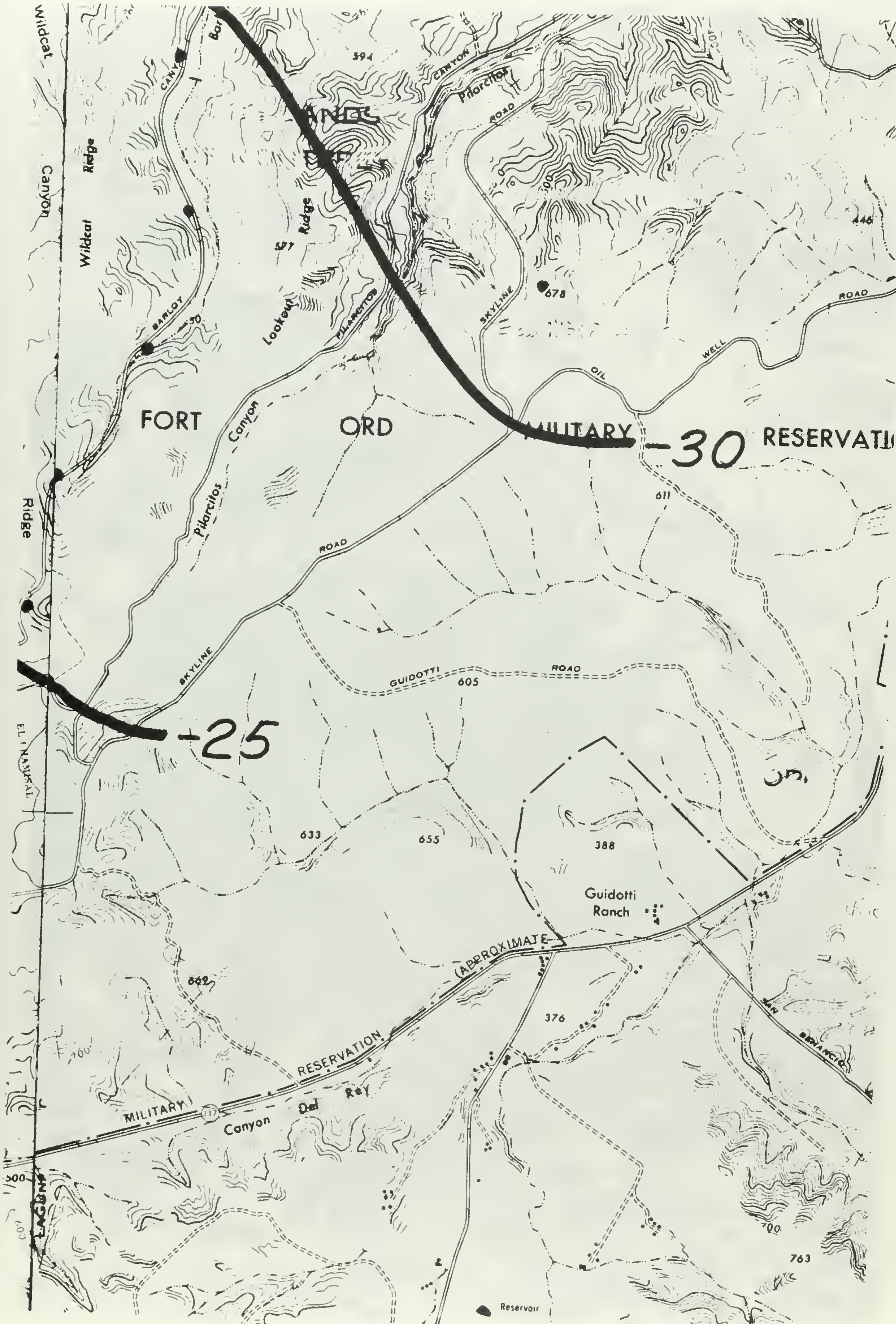


Fig. 25. Plate Vd

Fig. 26. Plate Ve

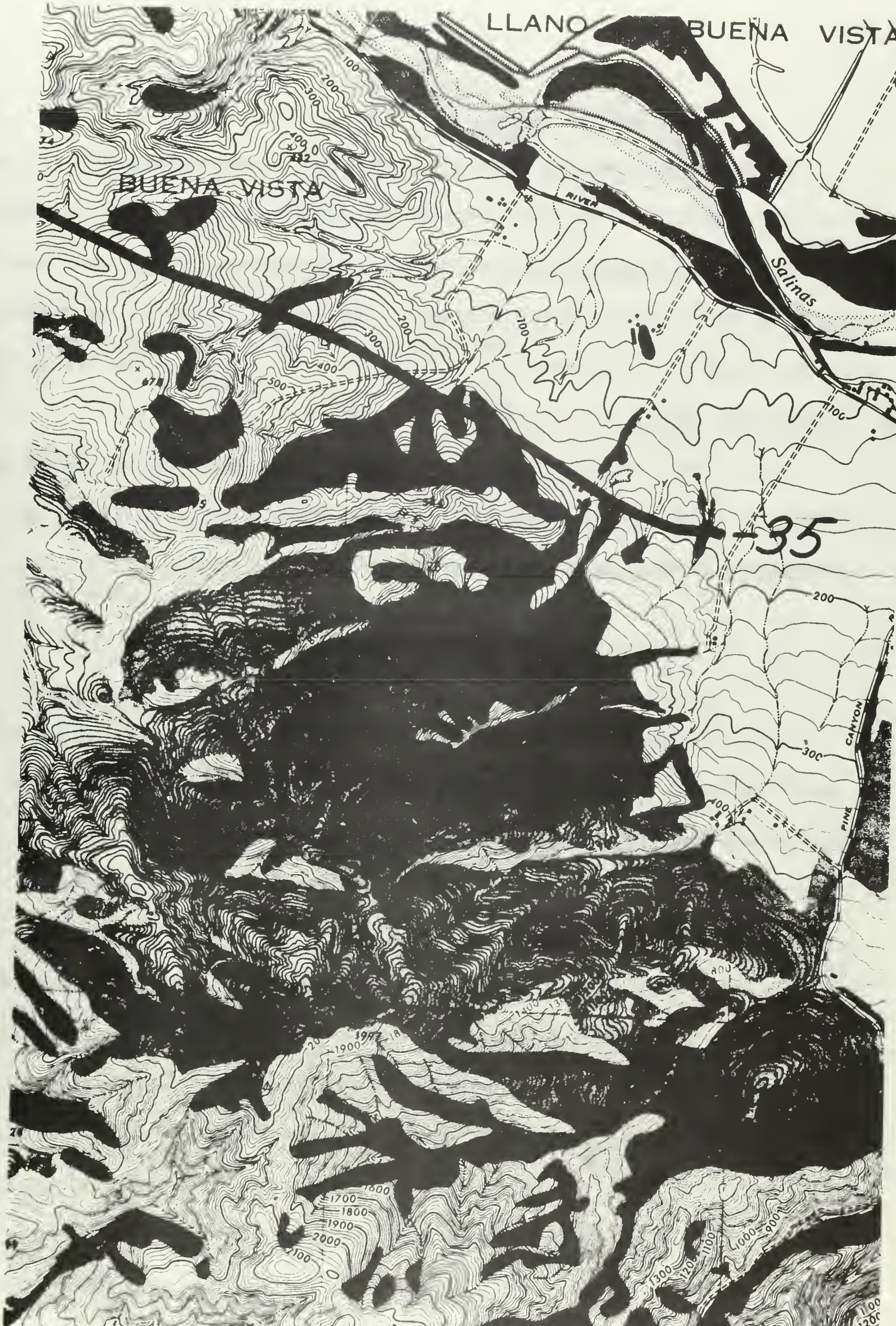


Fig. 27. Plate Vf

VII CONCLUSIONS

The strong low SBA on Fort Ord indicates a depressed area with an isostatic root which is overcompensated. In accordance with isostatic theory, it is expected that in the future this area should rise. As it rises the alluvium which presently covers the area will be removed. This process will continue until eventually the area is isostatically compensated.

A detailed cross-section of the substructure was not attempted because, as shown in Tables I and II, a reasonably accurate tie to the preceeding gravity work in the area could not be made.

VIII. RECOMMENDATIONS

It is strongly recommended that the entire Monterey Peninsula be resurveyed with a LaCoste-Romberg Model G Geodetic Gravity Meter or equivalent and the gravity anomalies be redetermined accurately. Once the anomalies are well known a more thorough understanding of the subsurface structure can be obtained

The only area on the west coast of the United States that has both the geology and negative anomalies consistent with the theory of sea-floor spreading is located basically along the Salinas Valley. Thus Monterey is ideally located to study this concept. It is recommended that the areas both to the east of Fort Ord on land and to the west at sea be surveyed to determine the full extent of the area of negative anomalies. This data in conjunction with a complete, accurate geological study of the same area should enable a full scale study of sea-floor spreading.

APPENDIX A

Derivation of the Free Air Correction

The normal gravity at any height h is expressed as:

$$g_h = g_o + \int_o^h \frac{\partial g}{\partial h}\, dh \qquad \text{(a)}$$

where g_o, g_h equal normal gravity on the reference sphere and at elevation h, respectively.

which expanded in a Taylor series gives:

$$g_h = g_o - \left(\frac{\partial g}{\partial h}\right)_o h + \tfrac{1}{2}\left(\frac{\partial^2 g}{\partial h^2}\right)_o h^2 - (1/6)\left(\frac{\partial^3 g}{\partial h^3}\right)_o h^3 + \ldots \qquad \text{(b)}$$

which can be written:

$$g_h = g_o + Ah + Bh^2 + Ch^3 + Dh^4 + \ldots \qquad \text{(c)}$$

where A, B, C, etc. correspond to the coefficients of the Taylor expansion.

Hirvonen [1960] developed the potential differences $u = u_o - u_h$ in terms of a Taylor expansion along the normal and since

$$\frac{\partial u}{\partial h} = g$$

and

$$\frac{\partial^2 u}{\partial h^2} = \frac{\partial g}{\partial h}$$

his results can be applied here.

Then

$$A = \frac{kM}{a^2 b}\left[2 + e^2 - m - \frac{27}{14} me^2 + e^4 - \sin^2 L(3 e^2 - 5m - \frac{23}{7} me^2 + 2e^4\right]$$

and

$$B = \frac{kM}{a^2 b^2}\left[3 - 5m + 2e^2 - \sin^2 L_o (9e^2 - 15m)\right]$$

where $m = \frac{\omega^2 a^2 b}{kM}$

k = universal gravitational constant

M = mass of earth

a = equitorial radius of ellipsoid

b = polar radius of ellipsoid

L = latitude

e = second eccentricity of international ellipsoid.

When constants for the International ellipsoid are used

$a = 637838800$ cm

$e^2 = 0.006722670022$

$m = 0.00344986385$ cm^3/gm - sec^{-2}

$\frac{kM}{a^2 b} = 1.541363543 \times 10^{-6}$ sec^{-2}

$A = -(0.308777237 - 0.000452063 \sin^2 L_o)$

$B = .07264891075 \times 10^{-6} - 0.00021230891 \times 10^{-6} \sin^2 L_o$.

Approximate the earth as a sphere of mass M and radius R, then considering only that part of the gravity due to the Newtonian attraction

$$g' = \frac{kM}{R^2}$$

the vertical rate of change of g with respect to R is

$$\frac{dg}{dR} = -2 \frac{kM}{R^3}$$

which corresponds to the main term of A.

Differentiation of the above yields

$$\frac{d^2g}{dR^2} = 6 \frac{kM}{R^4} .$$

which corresponds to the main term of B. Also

$$\frac{d^3g}{dR^3} = -24 \frac{kM}{R^5} .$$

At any point P_o on the earth's surface

$$g_o = \frac{kM}{Ro^2}$$

and thus

$$\left(\frac{d^3g}{dR^3}\right)_o = -24 \frac{g_o}{Ro^3} .$$

When

$$g_o = 980 \text{ gals}$$

$$R_o = 6371.2 \text{ km},$$

$$\left(\frac{d^3g}{dR^3}\right)_o = -9.094392 \times 10^{-8} \text{ gals/km}^3$$

and

$$C = -1.515732 \times 10^{-8} \text{ gals/km}^3 .$$

By the same procedure

$$\left(\frac{d^4g}{dR^4}\right)_o = 120 \frac{g_o}{R_o^4} = 0.71371096 \times 10^{-10} \text{ gals/km}^4$$

and

$$D = 0.029737957 \times 10^{-10} \text{ gals/km}^4 .$$

Collecting terms and converting height to feet and gravity values to mgal:

$$\begin{aligned} g_h = g_o & - (.0941154901 - .000137789 \sin^2 L_o)E \\ & - (.00674933167 \times 10^{-6} - 0.0001972422 \times 10^{-6} \sin^2 L_o)E^2 \\ & - 1.515732 \times 10^{-8} E^3 - \ldots \end{aligned} \qquad \text{(d)}$$

Truncating at 10^{-10} , the Free Air Correction is obtained from (d):

$$\begin{aligned} FAC = & (0.09411549 - 0.000137789 \sin^2 L)E \\ & - 0.0000000067 E^2 \end{aligned}$$

FORT ORD, CALIFORNIA SURVEY

BASE - CH259 GBV 979869.12 METER G58 READING 3296.04

STA	LATITUDE	LONGITUDE	ELEV	READING	T+D	OBSV-GRAV
CH259	36 35.23	121 50.89	171.8	3296.04	0.14	979869.12
CA879	36 36.15	121 49.56	235.7	3290.50	0.16	979863.40
CA884	36 39.28	121 47.08	245.0	3268.63	0.21	979840.81
CA883	36 39.25	121 48.48	169.1	3277.63	0.19	979850.11
IV 4	36 39.41	121 47.91	129.0	3277.18	0.17	979849.62
IV 5	36 40.11	121 48.34	107.6	3281.31	0.14	979853.87
IV 6	36 40.04	121 47.91	118.4	3279.49	0.14	979851.98
IV 7	36 39.62	121 47.69	183.9	3273.82	0.13	979846.10
IV 8	36 39.14	121 47.52	240.9	3270.13	0.12	979842.27

FORT ORD, CALIFORNIA SURVEY

BASE - CH259 GBV 979869.12 METER G58 READING 3296.22

STA	LATITUDE	LONGITUDE	ELEV	READING	T+D	OBSV-GRAV
CH259	36 35.23	121 50.89	171.8	3296.22	-0.01	979869.12
IV 9	36 36.14	121 47.34	541.8	3253.30	-0.02	979824.67
IV 10	36 37.25	121 48.35	543.4	3258.55	-0.03	979830.09
IV 11	36 35.39	121 46.31	929.5	3231.84	-0.02	979802.44

FORT ORD, CALIFORNIA SURVEY

BASE - CH259 GBV 979869.12 METER G58 READING 3296.13

STA	LATITUDE	LONGITUDE	ELEV	READING	T+D	OBSV-GRAV
CH259	36 35.23	121 50.89	171.8	3296.13	0.07	979869.12
IV 12	36 36.24	121 43.68	678.0	3236.98	0.10	979807.90
IV 13	36 37.13	121 44.64	259.9	3265.48	0.13	979837.44
IV 14	36 36.16	121 44.76	569.7	3250.10	0.13	979821.52
IV 15	36 37.39	121 45.10	308.0	3262.69	0.14	979834.56
IV 16	36 37.30	121 45.75	453.2	3255.20	0.15	979826.82
IV 17	36 37.30	121 46.10	406.5	3259.42	0.16	979831.20
IV 18	36 37.45	121 48.15	439.9	3265.26	0.17	979837.25
IV 19	36 37.68	121 47.76	464.3	3260.08	0.17	979831.89
IV 20	36 37.46	121 46.77	499.3	3254.19	0.16	979825.78
IV 21	36 39.68	121 45.22	191.0	3270.34	0.17	979842.51
CA890	36 39.34	121 43.84	131.0	3271.54	0.16	979843.75
IV 23	36 37.93	121 42.99	54.0	3274.19	0.15	979846.48
CA843	36 37.73	121 41.56	208.2	3262.02	0.14	979833.87

FORT ORD, CALIFORNIA SURVEY

BASE - CH259 GBV 979869.12 METER G58 READING 3296.12

STA	LATITUDE	LONGITUDE	ELEV	READING	T+D	OBSV-GRAV
CH259	36 35.23	121 50.89	171.8	3296.12	0.08	979869.12
IV 25	36 38.64	121 48.75	186.5	3278.32	0.09	979850.70
IV 26	36 38.65	121 48.33	249.8	3272.51	0.11	979844.70
IV 27	36 38.64	121 47.93	301.4	3267.80	0.10	979839.81
IV 28	36 39.28	121 48.03	188.0	3274.98	0.10	979847.25
IV 29	36 39.17	121 48.64	187.2	3277.07	0.11	979849.42

FORT ORD, CALIFORNIA SURVEY

BASE - CH259 GBV 979869.12 METER G58 READING 3296.10

STA	LATITUDE	LONGITUDE	ELEV	READING	T+D	OBSV-GRAV
CH259	36 35.23	121 50.89	171.8	3296.10	0.12	979869.12
IV 30	36 36.17	121 49.37	264.5	3285.74	0.12	979858.39
IV 31	36 36.89	121 49.22	315.7	3278.99	0.12	979851.40
IV 32	36 37.32	121 48.98	330.5	3274.98	0.11	979847.24
IV 33	36 37.80	121 47.44	435.7	3259.90	0.10	979831.62
IV 34	36 37.50	121 44.46	197.6	3268.93	0.10	979840.97
IV 35	36 36.74	121 44.68	333.1	3262.30	0.09	979834.09
IV 36	36 35.79	121 44.97	431.8	3257.76	0.08	979829.38
IV 37	36 35.59	121 45.02	758.8	3239.11	0.06	979810.05
IV 38	36 35.48	121 45.07	790.8	3237.69	0.06	979808.58
IV 39	36 35.15	121 45.40	797.9	3238.20	0.05	979809.09
IV 40	36 35.23	121 45.84	843.5	3236.18	0.04	979806.99
IV 41	36 35.06	121 46.24	796.5	3239.68	0.04	979810.62
IV 42	36 34.87	121 46.89	728.3	3245.28	0.03	979816.41

APR 3 1969

T+D 0.14 D1 2.67 D2 2.60

THEO-GRAV	FAA	BA1	CC	TC	CBA1	CBA2
979881.28	4.00	-1.86	0.08	2.86	0.92	1.00
979882.60	2.97	-5.07	0.10	2.70	-2.47	-2.33
979887.11	-23.25	-31.61	0.11	2.08	-29.63	-29.46
979887.06	-21.05	-26.82	0.07	2.13	-24.76	-24.67
979887.29	-25.54	-29.94	0.06	2.03	-27.97	-27.91
979888.30	-24.31	-27.98	0.05	2.02	-26.01	-25.97
979888.20	-25.08	-29.12	0.05	1.99	-27.18	-27.13
979887.60	-24.20	-30.47	0.08	2.33	-28.22	-28.12
979886.91	-21.97	-30.19	0.11	2.14	-28.15	-27.99

APR 4 1969

T+D -0.01 D1 2.67 D2 2.60

THEO-GRAV	FAA	BA1	CC	TC	CBA1	CBA2
979881.28	4.00	-1.86	0.08	2.86	0.92	1.00
979882.59	-6.96	-25.44	0.23	2.58	-23.09	-22.66
979884.19	-2.98	-21.51	0.23	2.80	-18.95	-18.53
979881.51	8.36	-23.34	0.39	3.92	-19.80	-19.07

APR 6 1969

T+D 0.07 D1 2.67 D2 2.60

THEO-GRAV	FAA	BA1	CC	TC	CBA1	CBA2
979881.28	4.00	-1.86	0.08	2.86	0.92	1.00
979882.73	-11.06	-34.18	0.29	5.00	-29.47	-28.99
979884.01	-22.12	-30.99	0.11	3.06	-28.04	-27.88
979882.62	-7.51	-26.94	0.24	2.88	-24.30	-23.86
979884.39	-20.85	-31.36	0.13	2.75	-28.74	-28.54
979884.26	-14.81	-30.27	0.20	2.48	-27.98	-27.64
979884.26	-14.82	-28.69	0.18	2.25	-26.61	-26.30
979884.47	-5.84	-20.84	0.19	2.46	-18.58	-18.24
979884.80	-9.24	-25.08	0.20	2.43	-22.85	-22.49
979884.49	-11.74	-28.77	0.21	2.55	-26.43	-26.05
979887.68	-27.20	-33.72	0.08	1.83	-31.96	-31.84
979887.19	-31.12	-35.59	0.06	1.92	-33.72	-33.66
979885.16	-33.60	-35.44	0.02	2.59	-32.88	-32.89
979884.88	-31.42	-38.52	0.09	2.89	-35.73	-35.61

APR 8 1969

T+D 0.08 D1 2.67 D2 2.60

THEO-GRAV	FAA	BA1	CC	TC	CBA1	CBA2
979881.28	4.00	-1.86	0.08	2.86	0.92	1.00
979886.19	-17.94	-24.31	0.08	2.29	-22.09	-21.98
979886.20	-18.00	-26.52	0.11	2.19	-24.44	-24.27
979886.19	-18.02	-28.30	0.13	2.20	-26.24	-26.02
979887.11	-22.17	-28.58	0.08	2.10	-26.56	-26.45
979886.95	-19.92	-26.30	0.08	2.24	-24.14	-24.03

APR 12 1969

T+D 0.12 D1 2.67 D2 2.60

THEO-GRAV	FAA	BA1	CC	TC	CBA1	CBA2
979881.28	4.00	-1.86	0.08	2.86	0.92	1.00
979882.63	0.64	-8.38	0.12	2.58	-5.92	-5.75
979883.67	-2.57	-13.34	0.14	2.60	-10.87	-10.66
979884.29	-5.96	-17.23	0.14	2.55	-14.82	-14.59
979884.98	-12.38	-27.24	0.19	2.52	-24.90	-24.58
979884.55	-24.99	-31.73	0.09	2.49	-29.32	-29.21
979883.45	-18.03	-29.39	0.14	2.88	-26.66	-26.43
979882.93	-12.94	-27.67	0.19	2.94	-24.91	-24.60
979881.80	-0.38	-26.26	0.32	3.29	-23.29	-22.69
979881.64	1.32	-25.65	0.33	3.27	-22.71	-22.08
979881.16	2.98	-24.23	0.34	2.93	-21.64	-21.00
979881.28	5.05	-23.71	0.35	3.27	-20.81	-20.13
979881.03	4.50	-22.66	0.33	3.15	-19.85	-19.21
979880.76	4.15	-20.69	0.31	2.96	-18.03	-17.45

FORT ORD, CALIFORNIA SURVEY

BASE - CH259 GBV 979869.12 METER G58 READING 3296.14

STA	LATITUDE	LONGITUDE	ELEV	READING	T+D	OBSV-GRAV
CH259	36 35.23	121 50.89	171.8	3296.14	0.12	979869.12
IV 43	36 34.83	121 47.28	704.5	3247.78	0.12	979819.04
IV 44	36 34.70	121 47.66	572.5	3257.00	0.13	979828.60
IV 45	36 34.65	121 48.05	429.1	3267.43	0.14	979839.41
IV 46	36 34.62	121 48.44	349.4	3272.95	0.14	979845.13
IV 47	36 35.01	121 48.92	230.9	3284.00	0.15	979856.58
IV 48	36 35.38	121 49.43	162.3	3291.47	0.15	979864.31
IV 49	36 35.62	121 49.87	139.3	3294.92	0.15	979867.89
IV 50	36 35.93	121 49.67	243.6	3289.83	0.16	979862.63

FORT ORD, CALIFORNIA SURVEY

BASE - CH259 GBV 979869.12 METER 143 READING 3432.61

STA	LATITUDE	LONGITUDE	ELEV	READING	T+D	OBSV-GRAV
CH259	36 35.23	121 50.89	171.8	3432.61	0.12	979869.12
CH258	36 40.43	121 39.36	50.0	3421.44	0.09	979857.40

FORT ORD, CALIFORNIA SURVEY

BASE - CH259 GBV 979869.12 METER 143 READING 3432.69

STA	LATITUDE	LONGITUDE	ELEV	READING	T+D	OBSV-GRAV
CH259	36 35.23	121 50.89	171.8	3432.69	0.07	979869.12
CA850	36 36.00	121 52.40	16.0	3449.54	0.05	979886.74
CA873	36 30.10	121 45.35	243.2	3422.63	0.04	979858.56
CA886	36 32.30	121 43.46	505.5	3394.33	0.04	979828.95
CA842	36 36.44	121 38.69	55.5	3407.81	0.06	979843.07
CA709	36 38.67	121 39.78	47.0	3410.66	0.07	979846.06
CH258	36 40.43	121 39.36	50.0	3421.40	0.07	979857.30
CA702	36 41.77	121 41.96	34.0	3423.85	0.08	979859.88
CA716	36 41.58	121 44.03	26.0	3421.69	0.09	979857.63
CA844	36 43.95	121 46.76	26.0	3426.12	0.10	979862.27
CA845	36 42.88	121 47.47	56.0	3422.27	0.11	979858.25

FORT ORD, CALIFORNIA SURVEY

BASE - CH259 GBV 979869.12 METER 143 READING 3432.83

STA	LATITUDE	LONGITUDE	ELEV	READING	T+D	OBSV-GRAV
CH259	36 35.23	121 50.89	171.8	3432.83	0.10	979869.12
CA847	36 39.68	121 48.97	86.6	3421.52	0.08	979857.26
CA849	36 37.80	121 50.10	90.0	3429.30	0.05	979865.38

NOTES:
'CH' STATIONS ARE CALIFORNIA DIVISION OF MINES AND GEOLOGY BASE STATIONS.
'CA' STATIONS ARE RECOVERED STATIONS ON THE SANTA CRUZ GRAVITY SHEET.
'IV' STATIONS ARE NEW STATIONS ON THE SANTA CRUZ GRAVITY SHEET.
GBV = GRAVITY BASE VALUE
T+D = TIDE PLUS DRIFT CORRECTION
OBSV-GRAV = OBSERVED GRAVITY
THEO-GRAV = THEORETICAL GRAVITY
FAA = FREE AIR ANOMALY
BA1 = SIMPLE BOUGUER ANOMALY FOR DENSITY 2.67
CC = CURVATURE CORRECTION
TC = TERRAIN CORRECTION
CBA1 = COMPLETE BOUGUER ANOMALY FOR DENSITY 2.67
CBA2 = COMPLETE BOUGUER ANOMALY FOR DENSITY 2.60

APR 13 1969

T+D 0.12 D1 2.67 D2 2.60

THEO-GRAV	FAA	BA1	CC	TC	CBA1	CBA2
979881.28	4.00	-1.86	0.08	2.86	0.92	1.00
979880.70	4.61	-19.42	0.30	3.45	-16.27	-15.72
979880.52	1.93	-17.59	0.24	3.04	-14.80	-14.36
979880.45	-0.67	-15.31	0.19	3.01	-12.48	-12.17
979880.40	-2.41	-14.33	0.15	2.85	-11.63	-11.39
979880.96	-2.66	-10.54	0.10	2.75	-7.89	-7.75
979881.50	-1.91	-7.45	0.07	2.78	-4.73	-4.66
979881.84	-0.85	-5.60	0.06	3.32	-2.34	-2.30
979882.29	3.25	-5.05	0.11	2.84	-2.33	-2.18

AUG 1 1969

T+D 0.12 D1 2.67 D2 2.60

THEO-GRAV	FAA	BA1	CC	TC	CBA1	CBA2
979881.28	4.00	-1.86	0.08	- -	- -	- -
979888.76	-26.66	-28.36	0.02	- -	- -	- -

AUG 2 1969

T+D 0.07 D1 2.67 D2 2.60

THEO-GRAV	FAA	BA1	CC	TC	CBA1	CBA2
979881.28	4.00	-1.86	0.08	- -	- -	- -
979882.39	5.85	5.31	0.01	- -	- -	- -
979873.90	7.53	-0.76	0.11	- -	- -	- -
979877.07	-0.57	-17.81	0.22	- -	- -	- -
979883.02	-34.73	-36.62	0.02	- -	- -	- -
979886.23	-35.74	-37.35	0.02	- -	- -	- -
979888.76	-26.76	-28.46	0.02	- -	- -	- -
979890.69	-27.62	-28.77	0.02	- -	- -	- -
979890.42	-30.34	-31.23	0.01	- -	- -	- -
979893.83	-29.11	-30.00	0.01	- -	- -	- -
979892.29	-28.77	-30.68	0.02	- -	- -	- -

AUG 3 1969

T+D 0.10 D1 2.67 D2 2.60

THEO-GRAV	FAA	BA1	CC	TC	CBA1	CBA2
979881.28	4.00	-1.86	0.08	- -	- -	- -
979887.68	-22.27	-25.23	0.04	- -	- -	- -
979884.98	-11.14	-14.20	0.04	- -	- -	- -

BIBLIOGRAPHY

Bishop, C. C. and R. H. Chapman. 1967. Bouguer Gravity Map of California (Santa Cruz Sheet). The California Division of Mines and Geology, San Francisco.

Chapman, R. H. 1966. The California Division of Mines and Geology Base Station Network (Supplement to Special Report 90). California Division of Mines and Geology, San Francisco. 4 p.

Dobrin, M. B. 1960. Introduction to Geophysical Prospecting. McGraw-Hill Book Company, Inc., New York. 446 p.

Grant, F. S. and G. F. West. 1965. Interpretation Theory in Applied Geophysics. McGraw-Hill, Inc., San Francisco. 583 p.

Hirvonen, R. A. 1960. New Theory of the Gravimetric Geodesy. Ann. Acad. Sci. Fennicae, A., III(56), Helsinki. 50 p.

LaCoste-Romberg. Instruction Manual for LaCoste and Romberg, Inc., Model G Geodetic Gravity Meter No. 58. LaCoste and Romberg, Inc., Austin, Texas.

Lambert, W. D. 1930. The Reduction of Observed Value of Gravity to Sea Level. Bulletin Geodesique. 26:107 - 181.

Scheibe, D. M. and H. W. Howard. 1964. Classical Methods for Reduction of Gravity Observations; ACIC Reference Publication No 12. Aeronautical Chart and Information Center, St. Louis, Mo. 65 p.

Service Hydrographique de la Marine and Compagnie Generale de Geophysique. 1968. Tidal Gravity Corrections for 1969. Geophysical Prospecting, Supplement 1. 16: 53 p.

Sieck, H. C. 1964. A Gravity Investigation of the Monterey - Salinas Area. Unpublished Student Research Project. Stanford University, Palo Alto, California.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	20
2.	Library, Code 0212 Naval Postgraduate School Monterey, California 93940	2
3.	Oceanographer of the Navy The Madison Building 732 N. Washington Street Alexandria, Virginia 22314	1
4.	Assoc. Professor J. J. von Schwind Code 58 Vs Department of Oceanography Naval Postgraduate School Monterey, California 93940	1
5.	Asst Professor R. S. Andrews Code 58 Ad Department of Oceanography Naval Postgraduate School Monterey, California 93940	1
6.	Mr. H. W. Oliver U. S. Geological Survey 345 Middlefield Road Menlo Park, California 94025	1
7.	Dr. R. H. Chapman California Division of Mines and Geology Ferry Building San Francisco, California 94111	1
8.	LCDR C. G. Ivey, Jr. USS Tang (SS 563) FPO San Francisco, California 96601	1
9.	Professor R. J. Smith Code 58 Sj Department of Oceanography Naval Postgraduate School Monterey, California 93940	1

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Naval Postgraduate School Monterey, California 93940	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

A Gravity Survey of Fort Ord, California

4. DESCRIPTIVE NOTES *(Type of report and, inclusive dates)*
Master's Thesis; October 1969

5. AUTHOR(S) *(First name, middle initial, last name)*

Clarence Gresham Ivey, Jr.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
October 1969	55	10

8a. CONTRACT OR GRANT NO. b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Naval Postgraduate School Monterey, California 93940

13. ABSTRACT

In April 1969, 50 different gravity stations on and around the perimeter of Fort Ord, California, were obtained using a LaCoste-Romberg Model G Geodetic Gravity Meter. The density of stations enabled accurate location of 5-mgal contours of Simple Bouguer Anomaly. The major differences found between the new and previously published contours occurred in the west and southwest regions of Fort Ord.

Five stations obtained by an earlier investigator were reoccupied during this study. The differences in observed gravity at these stations ranged from -0.37 mgal to -0.70 mgal.

In an attempt to explain the differences, 11 additional stations were reoccupied in August 1969. Observed gravity differences for these stations ranged from -0.05 mgal to -0.58 mgal. The differences could not be fully explained nor could the earlier study be successfully tied to this study.

Fort Ord lies on a gravity low and is isostatically overcompensated. Further gravity readings are required on the Monterey Peninsula and in the Salinas Valley to adequately define the substructure of Fort Ord.

DD FORM 1 NOV 65 1473 (PAGE 1)
S/N 0101-807-6811

Unclassified
Security Classification

A-31408

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Gravity Survey						
Fort Ord, California						
Simple Bouguer Anomaly						